A Game Theoretic Approach to Guarantee Fairness in Cooperation Among Green Mobile Network Operators

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ABSTRACT

Energy efficiency is one of leading design principles for the current deployment of cellular mobile networks. A first driving reason for this is that half of the operating costs for the network providers comes from the energy spent to power the network, with almost 80% of it being consumed at the base stations. A second reason is related to the high environmental pollution, which makes the green cellular networks deployment mandatory. Cooperation between mobile network providers can be an effective way to reduce the CO$_2$ emissions and, simultaneously, reduce the operating expenditures. In this paper, a game theoretic approach is proposed to introduce fairness and stability into an optimal algorithm for switching off the cooperating base stations. This aims at making such a solution more attractive in real implementation scenarios where profit-driven network providers act as rational players.

Keywords: Cellular Networks, Energy Efficiency, Fairness, Game Theory, Nucleolus, Provider Cooperation, Shapley-Value

INTRODUCTION

The evolutilional trend in the number of mobile subscribers has shown a constant rise over the years. Today it exceeds 5 billion and this number will continue to increase in the future. Although currently only 2-3% of the world’s carbon footprint comes from the ICT industry, this value is expected to reach the 15% in 2020 (Lee, 2010). Efficient energy usage and environmental-friendly energy production can limit the expected growth of CO$_2$ emissions: this is an excellent reason for the evolution in mobile networks to follow a green approach. At
the same time, energy efficient solutions are attractive from the network provider point of view, since half of the operating expenditures comes from the energy costs to power the network.

Several solutions have been recently proposed in this context, all of them are uniformly called green solutions, regardless whether they are about real consumption reduction or just feeding the old technology-based base stations by energy that was produced in a less polluting way. One simple and promising trend on the green direction, that can bring to immediate advantages in currently deployed networks, is the design of energy saving algorithms at the base stations (BSs). These methods have the huge advantage of a simple and cheap implementation that only requires a software upgrading without any need of new equipments. In particular, diagnosis and treatment of inactive periods of BSs can be exploited to temporarily switch off the stations with a low expected traffic. It is not only a matter of traffic reduction during nights and weekends, but the analysis of historical data has also been extended to forecast the changing intensity of mobile network usage within weekdays. It has been shown that residential areas usually become almost empty during the working hours (Bolla et al., 2010), thus enabling green solutions such as switching between access technologies, or turning off some of the carrier frequencies or the BS in low-traffic periods in some districts (Ajmone Marsan et al., 2008). Some solutions consider to introduce discontinuous transmissions or sleep mode when there is no need that all available BSs are simultaneously active, due to low traffic conditions. In Abdallah et al. (2012) a coordination policy for the sleep scheduling of neighboring Long Term Evolution (LTE) cells is proposed. Different schedules are compared showing the beneficial effects on the inter-cell interference during the sleep periods. In Bousia et al. (2012) the distance between the mobile terminals and their associated BS in an LTE-Advanced network is considered to design green solutions that minimize the energy consumption of the whole network. In Gong et al. (2010), the authors study how to dynamically (i.e., based on the blocking probability requirements) adjust the BSs’ working modes (active or sleeping) to save energy while meeting the system requirements.

Some interesting solutions can be designed when considering the presence of multiple providers in the same geographical area. In this case, cooperation among providers can be beneficial. The basic idea is to turn off one or more BSs when the traffic load is low in the covered area and can be managed by only a subset of remaining active BSs. In Ajmone Marsan, and Meo (2011) it is proposed to roam the subscribers among the overlapping network providers while some BSs are sequentially switched off, in such a way to cooperatively serve all the users. An optimal solution for the BSs switching-off sequence is found in Ajmone, Marsan, and Meo (2011) that maximizes the overall energy (and monetary) saving. Under the assumption of equal costs for all the providers in powering the network, independently of the number of served users, this solution simply corresponds to switch off first the BS with the lowest traffic load and then progressively the others in an increasing load order.

While this solution maximizes the overall savings for the pool of providers, the individual saving distribution is not fair. In fact, at least one provider (the most active one in the pool) will have no saving at all, since it will remain active to serve all the users for the best of the cooperative community. When considering a real world of profit-driven providers that act as “rational players”, some of them could judge such a solution not acceptable. This gives rise to a solution that is not stable.

The objective of this paper is to extend the proposal in Ajmone, Marsan, and Meo (2011) to make it more attractive in real scenarios with competitive providers. Specifically, the contribution in this paper is to propose a Transferable Utility (TU) game model for the problem, which keeps the advantage of the optimal solution found in Ajmone, Marsan, and Meo (2011) in terms of maximizing the overall energy savings, and also introduces fairness and stability in the
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